ARTICLE IN PRESS

Geotextiles and Geomembranes xxx (2017) 1–8

Contents lists available at ScienceDirect

Geotextiles and Geomembranes

journal homepage: www.elsevier.com/locate/geotexmem

Experimental evaluation of geosynthetics as reinforcement for shotcrete

R. Moffat [a,*], C. Jadue [b], J.F. Beltran [c], R. Herrera [c]

[a] Department of Civil Engineering, Universidad Adolfo Ibañez, Santiago, Chile
[b] Petrus Geotechnical Consulting, Dr. Roberto del Rio 1245, Providencia, Santiago, Chile
[c] Department of Civil Engineering, University of Chile, Blanco Encalada 2002, Santiago, Chile

ARTICLE INFO

Article history:
Received 5 May 2015
Received in revised form
4 January 2017
Accepted 4 January 2017
Available online xxx

Keywords:
Geosynthetics
Shotcrete
Geosynthetics reinforcement
Energy absorption
Shotcrete strength

ABSTRACT

One of the commonly used stabilization systems for rock tunnels is shotcrete. This fine aggregate mortar is usually reinforced for improving its tensile and shear strength. In deep tunnels, its capacity to absorb energy has been recently considered for design purposes, as large displacements of the wall are expected. Two of the most used materials of reinforcement are steel welded-wire mesh and fibers (steel or polypropylene) in the shotcrete mix. This study presents the results and discussion of an experimental test program conducted to obtain the load-deformation curves of reinforced shotcrete, according to ASTM C 1550, using geosynthetics grids and geotextiles as alternative reinforcement materials. In addition, plain shotcrete and steel welded-wire mesh reinforced shotcrete specimens are also considered in the experimental program as benchmark cases. The experimental results are analyzed in terms of maximum strength and toughness. Results show that the use of geosynthetics as a reinforcement material is a promising alternative to obtain shotcrete with energy absorption capacity comparable with the most common reinforcement materials used.

1. Introduction

Shotcrete has been used for more than 50 years in ground support applications. Before 1990 only a few research works had been published in scientific journals (Franzen, 1992) in which the main information reported was related to the mechanical properties of the shotcrete with little emphasis on how to consider the use of this material on the improvement of the safety of a tunnel. Some of the main design principles for ground supports are to sustain the loads and deformations that the ground may induce during a tunnel's working life, maintain adequate stability of the ground, and protect workers and equipment against rock falls (Hoek et al., 2000; The British Tunneling Society & The Institution of Civil Engineers (2004); Malmgren, 2005). The interaction between rock and shotcrete, however, is a complex issue. The performance, and consequently the load carrying capacity and deformability of the shotcrete, is influenced by a number of factors such as: the mechanical properties of the rocks, the rock stresses, the presence of rock bolts, the interface between rock and shotcrete, and the mechanical properties and thickness of the shotcrete among others (Hoek et al., 2000; Malmgren, 2005; Ansell, 2010; Austin and Robins, 1995; Galli et al., 2004). Hence, due to this complex interaction behavior, a combination of empirical (Bieniawski, 1994; Barton et al., 1974; Palmstrom, 1996) and analytical methods (Wood, 1975; Einstein and Schwartz, 1979; Hoek and Brown, 1980; Duddeck and Erdmann, 1984; Barret and Mccreath, 1995) along with the use of numerical analyses (finite, boundary, discrete, hybrid, and finite difference methods) can be used simultaneously in the various phases of analysis and design of shotcrete as ground support.

Shotcrete support design in tunnels strongly relies on the assumed type of rock failure mechanism that governs loading environment and shotcrete behavior, in which the latter can be classified in adhesion failure, bending failure, direct shear failure, punching shear failure, compressive failure, and tensile failure (Barret and Mccreath, 1995). The fundamental goal of shotcrete design is to create a self-supporting arch, comprised of shotcrete and other support components such as rock bolts, grouted rebars, meshes, and cables to resist the imposed loads and deformations. In particular, in tunnels located at large depths, the rock support

* Corresponding author. Diagonal Las Torres 2640, Peñalolén, Santiago, Chile.
E-mail addresses: ricardo.moffat@uai.cl (R. Moffat), cjadue@petrus.cl (C. Jadue), jbeltran@ing.uchile.cl (J.F. Beltran), riherrer@ing.uchile.cl (R. Herrera).

http://dx.doi.org/10.1016/j.geotexmem.2017.01.007
0266-1144/

system should allow the occurrence of an admissible displacement of the tunnel walls while preventing the collapse of the tunnel. In this condition, the relevant characteristics of the shotcrete to consider are: its deformability at the maximum displacement, and the strength at that displacement. In this case, the design does not look for a rigid support that maintains the original stress condition around the tunnel, but allows deformation transferring energy from the rock to the shotcrete lining (Matsumoto and Nishioka, 1992).

Following the idea that the shotcrete lining gradually deforms and balances the ground movements after excavation of a tunnel, the popular NATM (New Austrian Tunneling Method) was first conceptualized and used in the Tauern Tunnel in Austria in 1972 and later related to the concept of ground reaction curve (Brown et al., 1983) as shown in Fig. 1. Depending on the stress-displacement behavior or capacity to absorb energy of the reinforcement on the tunnel, there can be three different situations: Case A: the capacity of the support system is high enough to stop the deformation of the tunnel at low displacements (δ1); Case B: the support system has the capacity to stabilize the tunnel at large displacement (δ2) when the ground reaction curve has lower energy and pressure; and Case C: the support system does not have the capacity to stabilize the tunnel walls. It is important to point out that Case B and C have the same peak strength; however only Case B is able to generate a safe condition even if large displacements may be required. The principles of this method have been applied in different projects around the world. The design of fiber reinforced shotcrete as a primary support for a 10 m diameter tunnel on weak rock (Jovicic et al., 2009) and the idea that mine openings have to tolerate large deformations as a result of changes in stress due to mining activity (Vandewalle, 1998) are some examples of the application of this principle. It is important to point out that in this last application, it was emphasized that the ductility of the shotcrete lining can be measured by testing the moment bearing capacity of a shotcrete beam specimen and deducing an energy absorption capacity from the load displacement curve.

Following the aforementioned idea of energy absorption capacity, a shotcrete property utilized for design purposes in underground mines is based on what has been called toughness (post-crack ductility). It is mentioned in (Papworth, 2002) that it is necessary to consider toughness requirement in widely used design tools such as the Barton Chart and also recommended the use of round panel tests (such as ASTM C1550, 2012) where central deflection is measured when a load is applied to the disc (see Fig. 2) for its computation. A modified Barton chart is proposed where energy absorption deduced from testing is considered in order to determine the necessary shotcrete thickness. This would allow considering different types of shotcrete reinforcement in the design of shotcrete for underground rock tunnels. Consequently, reinforced shotcrete has been increasing its importance in terms of its capability to absorb larger amount of energy or displacement of the rock.

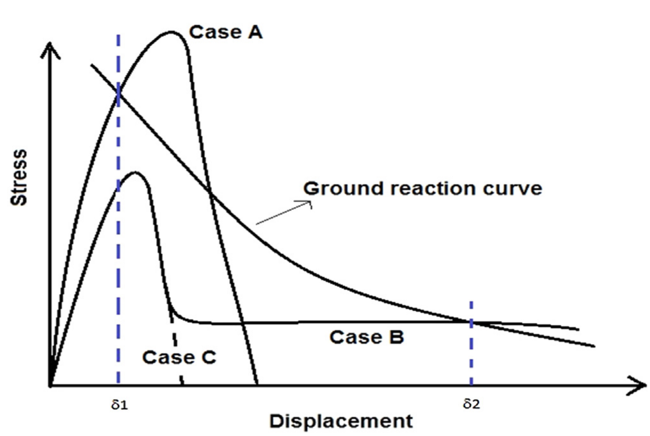

Fig. 1. Interaction between ground reaction curve and support performance.

1.1. Geosynthetics as reinforcement

Many studies have reported the beneficial effect of the geosynthetics reinforcements in geotechnical applications; construction of embankments over soft foundations soils (Fun and Hsieh, 2011; Rowe and Taechakumthorn, 2011; Karim et al., 2011; Zhuang and Wang, 2015; Chen et al., 2016); mitigation of hazardous effect of repeated loading on buried pipes (lifelines) (Mehrjardi et al., 2012; Corey et al., 2014; Hedge and Sitharam, 2015, 2016); improvement of pavement and rail track performance (Indraratna et al., 2010; Roodi and Zornberg, 2012; Zornberg, 2012; Yang and Han, 2013; Wu et al., 2015); stone columns improvement with geogrid encasement (Dash and Bora, 2013; Almeida et al., 2014; Hong et al., 2016); and stabilization of earthen walls and slopes (Silva et al., 2011; Yang et al., 2012).

In the particular case of reinforced shotcrete design, several experimental studies (Kirsten, 1998; Cengiz and Turanli, 2004; Morton et al., 2009; Mardookhpour, 2012; Kaufmann et al., 2013; Deng et al., 2016) have been conducted to evaluate the impact of using synthetic materials as reinforcement on shotcrete properties. Similar studies have been performed for reinforced concrete using polymers (El-Sayed et al., 2012; Mahmoud and El-Salakawy, 2015, 2016; Serna et al., 2016). These studies have shown that synthetic materials significantly improve ductility in the post-crack region and flexural toughness of plain shotcrete, offering an alternative solution to the traditional steel reinforcement (fibers and mesh). For example, a shotcrete reinforced with 0.78% of polypropylene fibers (volume occupied by the fibers in 1 m^3 of shotcrete) showed better post-crack performance (in terms of peak load and toughness) than a 0.45% steel fiber reinforced shotcrete, based on the results given by a panel test (Cengiz and Turanli, 2004). In addition to provide comparable post-crack performance to steel fiber reinforced shotcrete and increase shotcrete layer built-up thickness relative to the use of steel fibers (Dufour et al., 2006), synthetic materials are highly resistant to corrosion and they are safer, lighter, and easier to handle than steel (Yin et al., 2015).

Regarding the use of synthetic materials to reinforce shotcrete, experimental works have been mainly focused on the effect of macro synthetic fiber (polypropylene, aramid, high-density polyethylene, polyethylene terephthalate) on post-crack shotcrete performance. This performance is mainly influenced by the rebound of the fiber and material and also by the amount, distribution and orientation of the fibers, parameters that are determined by the application technique of the composite (Kaufmann et al., 2013). Although mixing processes have been improved and fiber manufacturers have developed new fiber geometries to prevent fibers clumps from forming, fiber clumps can still be observed in shotcrete, decreasing the toughness performance of the composite (Fig. 2).

Similar to synthetic macro fiber, geogrids and geotextiles could also be considered as a non-corroding alternative to steel mesh and fibers, but they eliminate the problem of clumps. In addition, geogrid and geotextile reinforcement may be oriented favorably with respect to the expected forces on the shotcrete in order to bridge the tensile forces to control crack development.

In this paper, an experimental study of the behavior of shotcrete reinforced with different types of geosynthetics is presented. A series of 35 ASTM C1550 round panel tests were carried out on

Please cite this article in press as: Moffat, R., et al., Experimental evaluation of geosynthetics as reinforcement for shotcrete, Geotextiles and Geomembranes (2017), http://dx.doi.org/10.1016/j.geotexmem.2017.01.007